Groundwater behaviour on the Eparses Islands

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ABSTRACT

Recent works have evidenced that climate changes will have noticeable impacts on small island. Their groundwater resources highly sensitive to seawater intrusion, are specially concerned. The Eparses Islands (Indian Ocean) may correspond to these systems. Hence, they have been chosen to implement groundwater monitoring stations as part of climate changes observatory. For this purpose, we proceeded to preliminary hydrogeological investigations, including description of hydrogeological systems and chemical analyses of groundwater. Salinity values in groundwater suggest heterogeneous variations within a brackish water lens. Geological structures are identified as the main factor forcing the seawater encroachment. The hydrogeological system consists of porous coral sand overlying reef limestone. Fractures in the karst promote the dispersion of salinity values. The groundwater compositions are located on the theorical freshwater- seawater mixed line, which suggests that Eparses Islands have a simple hydrochemical system highly sensitive to climatic and oceanic influences. If so, the global sea level change could be better evaluate by implanting monitoring stations on these islands.

INTRODUCTION

An important consequence of climate changes and sea level rise is the penetration of seawater into coastal aquifers (Bates *et al*., 2008). From this point of view, small tropical coral islands are very sensitive to climate changes (Vacher, 1997; White *et al*., 2007). Among them, uninhabited islands are the most suited settings to study the hydrogeological impact of climate changes because they are devoid of anthropic activity. Accordingly, the Eparses Islands may be an ideal environment to monitor the salinity evolution on aquifer due to climate changes. In this purpose, we have investigated the hydrogeological behaviour of these Islands. The mixing processes in groundwater between fresh and seawater are described to assess the salinity distribution.

Background

The Eparses Islands (Indian Ocean) are a group of 5 inhabited islands; we focus on three of them (UICN, 2009) (Fig.1). Europa (30 km^2), Juan de Nova (5 km^2) and Les Glorieuses (7 km^2) (Mozambique Channel) are subject to a tropical climate with two seasons: a humid (November-March) and a dry season (April-October). They are made of carbonate rocks (limestone and sand) deposited from the Pleistocene to the late Holocene (Camoins *et al*., 2004; Yamano *et al*., 2001). These islands can develop a karstic aquifer in the limestone rocks and eventually a porous sand aquifer in the detritic carbonate sediments (Schneider and Kruse, 2003). The saltwater intrusion is strongly determined by geological heterogeneities of these islands (Bailey *et al.*, 2009).

METHODS

In order to map the salinity distribution on each island, waters have been sampled from April to May 2009 (in dry season) (Tab.1). Samples came from rimmed pools for the karst aquifer or from existing wells (Juan de Nova) and auger wells (La Grande Glorieuse) for the porous aquifer (Fig.1). During the sample period, the tidal ranges are 2 meters for La Grande Glorieuse and 3,5 meters for Juan de Nova and Europa. Tidal fluctuations are observed in all sites and samplings have been made during the low tide. The electrical conductivities (EC) are measured and referenced in Table.1. On each of the collected samples, the concentrations of major and minor dissolved elements are measured by high performance liquid chromatograph, using a DIONEX ICS 1000 at Reunion University. The rainfall composition, sampled in La Grande Glorieuse, and the seawater mean composition was used to the threshold respectively value for fresh and salt groundwater.

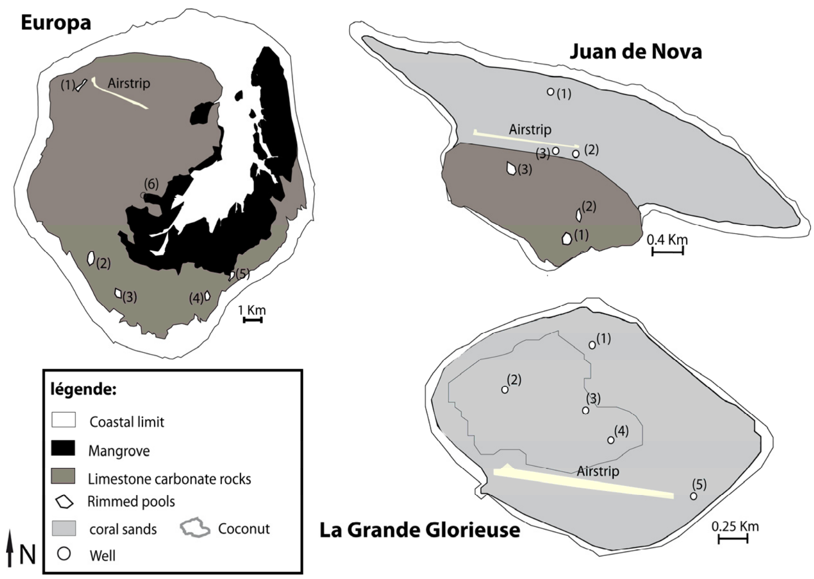

Figure 1: Sampling sites on the Eparses Islands; the numbers correspond to samples detailed in Table 1.

RESULTS

Hydrogeological settings

Europa is entirely made of carbonate limestone rocks (Fig.1). This island shows signs of intense karstification: lapiaz topography, aven in a south of the mangrove and rimmed pools (Battistini, 1966). For Europa, the EC shows values ranging from 49 900 to 64 400 μS/cm (mangrove) (Tab.1), comparable to seawater (56 000 μS/cm). To contrast, Juan de Nova exhibits the two types of formations (Fig.1) and the EC shows values ranging from 18 380 to 38 400 μS/cm (Tab.1), the value decrease when the distance to the sea increase (Tab.1). In La Grande Glorieuse, the limestone rocks are almost entirely covers by the detritic coral sand. The EC varies from 4 600 to 39 400 μS/cm. The lowest values were measured in two different locations: at the centre of the island (Well 3) and in south- eastern part of the island (Well 5). The EC spatial distribution presents no clear relationship with the distance inland from the shorelines (Fig.1) (Tab.1).

Table 1: Electrical conductivity of water on Eparses Islands.

Nam	*Rainfall (mm)*		*Samples*		*Distance to the sea (km)*	*EC (µS/cm)*
	Sum annual (2009)	*Sum April-May (2009)*				
Europa	484,4	11,8	karstic limestone rocks	rimmed pools	1,5	51 350[(a)]
				Mangrove (1)	1	64 400
Juan de Nova	519,4	7	karstic limestone rocks	rimmed pool (1)	0,36	38 400
				rimmed pool (2)	0,5	35 600
				rimmed pool (3)	0,7	28 600
			Sand porous aquifer	Well (1) [(b)]	0,5	35 300
				Well (2)	1	18 380
				Well (3)	1	20 400
La Grande Glorieuse	*738,6*	*195,3*	Sand porous aquifer	Well (1)	0,7	39 400
				Well (2)	1,4	36 900
				Well (3)	1,6	9 300
				Well (4)	1,7	28 000
				Well (5)	0,35	4 600

[(a)] Average of 6 samples from different locations of the Island, minimum and maximum values respectively 49 900 and 52 400 µS/cm (ranging from low tide and high tide).
[(b)] Well: in Juan de Nova: old open wells (diameters: 1,36 m, deep: 3 m), in La Grande Glorieuse: observation wells (diameter: 3 cm, deep: W(1) 4,025 m, W(2) 2, 95 m, W(3) 2,45 m, W(4) 1m and W(5) 3,6 m).

Hydrochemical analysis

All samples present sodium chloride (Na-Cl) facies. The correlation coefficients between the different elements (Na/Mg, K/Mg, Na/K, Na/SO4, Mg/SO4, Br/Cl, EC/Mg, EC/Na, EC/K) are all above 0.90. As an example, the Figure 2 shows a graph of Na versus Cl (meq / L). The samples are located on the theorical freshwater- seawater mixed line. The evolution of the samples concentrations is attributed to the relative seawater influences on groundwater.

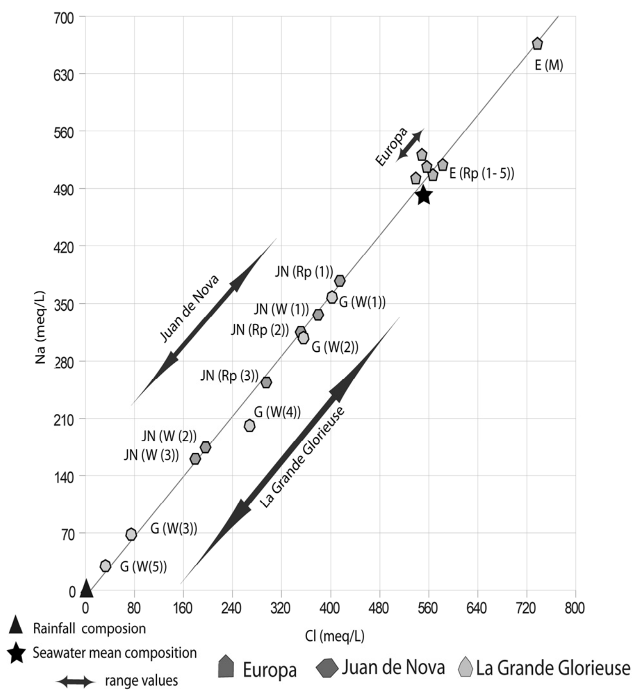

Figure 2: Hydrochemical relationships between all water samples to the Eparses Islands and seawater mean composition (Na= f (Cl) in meq/l)) (Software "DIAGRAMME" (Simler, 2010)).

DISCUSSION AND CONCLUSION

The three islands were sampled during the dry season with low rainfall rate and minimum flow conditions that enable to compare them. In Europa, the high hydraulic conductivity (K) of the karst aquifer favours the seawater intrusion and prevents the occurrence of a freshwater lens. Juan de Nova shows the same signs of karstification, has a similar rainfall values and same tidal forcing. However, the EC values are generally lower. In the eastern part, the progressive development of the porous aquifer with low K permits the storage of rainwater and limits seawater intrusion. This phenomenon is confirmed in La Grande Glorieuse Island, with differences on average EC values due to the highest rainfall values. The highest values recorded does not correspond to samples located approximated to the coast, meaning the brackish water lens is heterogeneous and depends of the detritic coral sands distribution. The hydrochemical analyses reveal simple reactions into the aquifer mainly influenced by the tidal forcing and climatic conditions.

The groundwater behaviour in island is traditionally represented by a homogeneous freshwater lens floating above the seawater and based on the immiscible fluids assumption of Ghyben-Herzberg, 1901. However, in small coral islands, the lens area is limited and tide controls the flow patterns. The dispersion phenomenon is intense and cannot be neglected. The mixing zone is extended to the whole island and is represented by a brackishwater lens (Oberdorfer *et al*., 1990). The lens distribution is evaluated by the “dual aquifer model” in relationship with the two different values of (K) (Bailey *et al*., 2009). The high K of the limestone promotes the seawater encroachment and truncates the lens in sand aquifer (Schneider and Kruse, 2003). The lens shape is asymmetric and heterogeneous, and depends on the depth of the limestone aquifer, that make each islands groundwater conditions are unique (Bailey *et al*., 2009).

In the Eparses Islands, monitoring wells to assess the groundwater evolutions due to climate changes should be of a great interest. Monitoring stations will be implemented in area where the sand thickness is more developed and the limestone rock is located deepest below the sea level.

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